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Forensic entomology is the study of arthropods concerning their application in crime scene investigation as a method of predicting postmortem interval (PMI) in deceased or missing individuals. PMI is determined by the life stage of insects present on-scene. Insects used in criminal investigations are primarily beetles, flies, or moths; this may also include various scavenging insects and hitchhiking mites. These creatures help colonize decayed tissue, providing crime scene personnel with live specimens collected and examined for biological evidence. Forensic entomology is currently a niche application in most investigations—as qualified entomologists are often needed—and proper analysis of collected evidence can be complex; however, with time, this forensic subdiscipline can be increasingly valuable as insect populations rise alongside global temperatures.

Keywords

entomology, postmortem interval, insects, crime scene investigation

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Introduction

Forensic entomology—formally known as the application and study of insect and other arthropod biology to criminal matters—is slowly becoming a more prevalent tool in solving crime in the modern world. Insects provide valuable insight into the rate of a corpse's decomposition, as well as clues to triangulate a victim's last known location. Additionally, they can be captured and examined on-scene or off-site to frisk for a victim's DNA with greater ease and legality than a human perpetrator. Insects also do not require specialized training. Civilian and CSI unit personnel easily learn basic specimen collection—and insects reliably colonize all aspects of a body—making them more readily available for collection due to their widespread availability and large population numbers. For these reasons, forensic entomology should be a more commonly applied crime-solving technique.

Literature Review

"Determination of post-burial interval using forensic entomology: a review"

Forensic entomology is an important subdiscipline of forensic science, primarily used for estimating the postmortem interval (PMI), or time elapsed since death, of a deceased individual by studying decomposition stages, successive patterns of arthropods (insects) over time, or estimating the approximate ages of immature insect specimens found on-scene. However, forensic entomology is still relatively unexplored, requiring further studies to better understand its use in field and lab work.

The dominant reason for using insects in death investigations is to find corpses. After committing a murder or witnessing an unlawful death, the perpetrator usually attempts to dispose of, or

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hide, the evidence for fear of repercussions. Bodies are commonly hidden by burial; however, the perpetrator often underestimates the amount of effort needed to make a proper trench, which generally results in shallow graves. Nearby insects then colonize these bodies— mainly beetles and flies— whose distinct life cycles can be directly related to different decomposition stages. Through these insects, forensic personnel determine a number of issues related to the deceased individual, such as the deceased's approximate postmortem interval (PMI), the sanitary conditions of the crime scene and the deceased, possible food or drugs in a victim's system, and the presence of physical abuse or neglect (Viero et al., 307-316.). Factors that affect how insects impact bodies include weather, environmental changes, or physical obstacles (e.g., water or plastic). Burial environments directly affect bodies through multiple factors: the presence or absence of a coffin, shroud or clothing, depth, soil composition— pH, temperature, moisture levels —and the body's physical condition (Lowe et al., 2013).

Forensic entomology's use with cadavers is long known, though as with all sciences, information is constantly reassessed and added. Exemplified in a 1985 study, six un-embalmed cadavers decomposed naturally in unlined trenches at different soil depths (Rodriguez & Bass, 1985). Data collected via samples from the surrounding air, soil, and temperature of the cadavers at each site. After each burial period ended, the cadavers were exhumed and examined for decomposition progress and changes to their surrounding soil. The results concluded that decomposition rates for corpses highly depend on burial depth and surrounding temperatures, directly affecting soil pH levels, carrion insect access, and available vegetation.

In 1999, another study documented the behavioral and life cycle patterns of blowflies that colonized pig liver covered in loose soil, observing factors included flies exploiting buried remains (and their larvae to develop on said remains), and how burial influences the pupation (cocooning) of flies. The resulting data helps determines if a body had previously been stored above ground before burial as the study's flies were drawn to the bait's fresh blood but did not try burrowing into the soil beneath, indicating a preference for freshly dead tissue (Gunn & Bird, 2011). This preference can help investigators determine a more accurate PMI for any recovered decedents, which can help narrow down the approximate time of death, and by association, how many individuals who died in that timeframe physically resemble the recovered person, helping with postmortem identification.

In 2006, Italy charged the father of two missing children with homicide, kidnapping, and concealing two bodies, seventeen months after a search by investigators and townspeople failed to find the missing children. Three months after the father's conviction, a fireman found the two victims well-preserved in a dry underground, cistern and identified from their dental records. Forensic entomology helped determine their approximate PMI through tracking dehydration rates with beetles as a gauge. Ultimately, the PMI findings helped exonerated the father of the homicide charges (Introna et al., 2011).

Situations involving chemicals or physical barriers hamper insects' use in body recovery and identification, as noted in the 2012 Belgian case cataloging the search for human remains buried with lime—a common ingredient in cement mixes (Schotsmans et al., 2012). The study's pig subjects were buried in several lime mixes in shallow soil graves against a lime-free control. The pigs were exhumed after six months and had a visibly slower rate of

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decay in the quicklime and hydrated lime graves compared to the lime-free graves, suggesting chemicals can delay or even prevent insect colonization. Situations such as this prevent insects from easily accessing a decaying body, requiring further research to understand the full effects of chemical and physical barriers on insect colonization (Bhadra et al., 2014. 239, 62-72).

Forensic entomology possesses increasing significance in criminal investigations, especially regarding forensic burial entomology. Insects' vital contribution to understanding and determining deceased individuals' PMI makes them invaluable to crime scene investigation. It emphasizes continuing entomology studies and the cataloging and updating these studies' combined results for research and fieldwork purposes in the future—particularly the marked obstruction of colonization by physical obstacles or chemicals.

A Discussion of Forensic Entomology in the Field

The use of insects as crime-solving tools primarily revolves around their application in finding and examining cadavers. They generally prefer freshly killed or decaying flesh over live tissue and will be found in increasing quantities the longer the body decays in one place, which can help investigators find the body and estimate how long since death occurred.

Obtaining live specimens on-scene— except flesh flies, which require thicker protective gear—requires no special training and minimal equipment, ensuring that CSI persons can learn collecting insects for transport and analysis quickly and at low cost. Insects also benefit from possible storage as frozen or pinned specimens for long-term close examination in a lab environment,

saving storage space for larger evidence such as a victim's personal possessions, soil and foliage samples, or even the murder weapon. Most standard CSI toolkits already contain the tools needed for insect, including labeled collection vials, latex gloves for handling evidence, forceps for small items, cameras for photographic documentation of the scene and any insects present, rulers for a measurement scale, and pencils or pens for writing pertinent information on each vial for lab analysis (Brundage & Byrd,
2016).

Insects or pollen found on cadavers, if found non-native to the area, can be compared to the closest geographical location with insects or pollen and examined for signs the body was moved from there. The life stage of at least one of the non-native insect specimens can also be examined to gauge approximately how long ago the body was moved. A corpse may attract different insect species depending on the stage of decay, meaning multiple insect species may choose to visit, inhabit, and feed on the corpse over long periods. The successive insect waves provide an approximate timeline of infestation, with flies generally arriving and laying eggs first, then beetles, then moths and other insects (Anderson, 2004).

Investigation of a crime scene using forensic entomology involves the finding, collecting, and possible identification of a deceased individual's remains using insects. Generally, there are two main methods of insect use to determine an approximate time lapse since death: successive waves of insects or maggot age and development.

Maggots provide information on general corpse freshness by collecting and examining maggot specimens, eggs, and egg cases to determine the life stage, which helps gauge the approximate

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start of body colonization. Anderson (2004) states that, for corpses dead for between a month and up to a year or more, successional insect waves are used; the second method—using maggot age and development as an approximate time frame—is used when the death occurred less than a month before discovery. Insects inhabiting a corpse need to make incision points for entries and exits, and the resulting orifices are usually made in soft tissue—such as through skin covering a strip of muscle. Soft tissue rots faster than hard tissue such as bone and is prone to external trauma such as bruising or tearing that can make convenient entrances for hungry insects.

Forensic entomology is not limited to use with the dead; it can also be used in cases of neglect or abuse of the living, primarily of children or the elderly, or even of animals. Head lice and maggots are notable specimens in such cases, often appearing in large numbers. Maggots will appear in neglect cases due to untreated injuries or unhygienic conditions on a living person, creating colonies that eat dead or dying tissues. For neglected toddlers, impaired elderly, and infants a maggot infestation helps determine a minimum time-lapse since the affected child or impaired adult last had a clean diaper change, as the unhygienic conditions result in cutaneous myiasis—a maggot infestation caused by unclean conditions and open wounds (Anderson, 2004).

Head lice serve as another abuse indicator, colonizing the scalps of individuals neglected for long periods. Nits— also known as lice eggs— used as markers for the length and frequency of neglect episodes and are laid by head lice (scalp infestation) and body lice (clothes infestation). Head lice form nit clusters only in severe infestations due to lack of available scalp room—changing from head to body lice—or supporting both simultaneously, requiring continuous lice infestation and re-

exposure. Lice found at crime scenes can also be examined to compare their most recent blood meal's DNA contents to the collected DNA of suspects or victims (Lambiase & Perotti, 2019). In the case study found in *Using human head lice to unravel neglect or cause of death*, researchers followed an elderly neglect victim presenting with a lice infestation severe enough that—prior to discovery and hospitalization—the egg-laying behavior from the lice present indicated that the victim had sustained about two years of continuous neglect. Hospital staff found body lice were present down to the torso, and the victim's head exhibited *plica polonica*, a symptom of severe head lice wherein scalp hairs become malodorous and glued together (2019).

Insects also aid in determining long-term neglect or abuse of animals. Maggot colonization of live animals can be used as evidence of neglect. Regarding neglected animals, fur is generally the first part of an animal to be infested, as it occupies a large surface area. "Areas of trauma, if present, may be colonized first" (Brundage & Byrd, 2016, p. 899). In such cases, veterinarians collect insect samples, give appropriate medical care, and provide medical information regarding the animal's current condition. In the case of deceased animals, veterinarians perform necropsies to determine the presence of insects hidden within animal remains, allowing examination of any items or coverings found with the animal. The collection of any specimens from these necropsies is important because "insects found in wrappings may be different species from those observed directly from the remains or in a different developmental stage…" (Brundage & Byrd, 2016, p. 905).

Several insects are primarily found to colonize or eat corpses, two of which—beetles and flies—are found in large numbers across all inhabited continents. Flies are commonly known for

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their affinity for rotting flesh as food. Flesh flies, known for eating live animal flesh, are utilized in medical science as a method for treating gangrenous tissue but may also be useful in examining a recovered missing individual in case of a long-term untreated injury. The blowfly larvae that colonize a corpse will ingest small amounts of the drug as they grow and consume dead tissue, and the ingested drugs may delay larval development rates. Therefore, blowflies help determine deceased individuals' PMI and test for trace amounts of drugs in the victim's system due to poisoning or intentional ingestion for suicide; (Universiti Teknologi MARA [UiTM], 2014).

Moths may use cloth fibers found on cadavers as an additional food source, and if a body is sufficiently dry and brittle, may choose to nest inside an available body cavity. Their furred wing scales may also be found dusted across clothing surfaces or skin, making it possible to identify certain species based on scale patterns. Beetles are found mainly in two categories regarding human corpses: skin beetles (*Dermestidae*) and bone beetles (*Cleridae*), with both also found buried in muscle tissue. These beetles can be present in varying quantities in decomposing remains—more commonly in dried bodies than wet—with most species being scavengers willing to eat, among other animal products: the skin, hair, various fibers, and the remains of other animals and insects when available (Jacobs, 2013).

There are several drawbacks to the use of forensic entomology for criminal investigation. For example, insect species may die unexpectedly before proper analysis, collection of live specimens may be made impossible due to the condition of the deceased or inappropriate equipment for safe collection and transport, or there may not even be any insects to be found in any life stage even

when the deceased is located. Insects require specific temperature and humidity ranges for optimal breeding, and if these ranges are unmet, the body may exhibit little to no maggot or live insect specimens to use. Cold-weather areas are thus more suitable for working with cadaver dogs instead of employing insects, especially as they also have the added benefit of scenting decomposition with their highly sensitive noses (Anderson, 2004).

Improper handling and collection of specimens for study can result in damage or death of specimens—or even damage to the deceased individual, depending on the extent of colonization—which can ruin evidence. However, given the sheer numbers of insects that colonize a body and the relative ease of basic collection, mistakes can be minimized. The disposal method of a victim's body affects insect colonization—or lack thereof. Bodies previously frozen need to be adequately exposed to the elements before insects can find and invade it—otherwise, the tissue is too hard to colonize. If the body has been wrapped or otherwise mummified with tarps, clothing, plastic, etc., the wrapping must be completely sealed to prevent infestation. Finally, buried bodies can have colonization impeded by the depth and soil composition. However, they may still be colonized even in deep graves if bodily fluids leak into the soil to entice insects (Anderson, 2004). In such cases, the use of certified diving teams, cadaver dogs, and region-specific professionals may be sought out as needed.

A certified forensic entomologist is highly recommended for cases involving insect use and study beyond basic fieldwork, which can be difficult as forensic entomology is a highly specific subdiscipline that demands education at a school with a certified forensic entomology program. The specialization required causes most cases involving insects to require flying in such specialists

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as needed; however, with sufficient training of CSI units regarding field collection and transport of specimens to an appropriate lab, they can substitute if no entomologist is available.

The use of forensic entomology in ongoing investigations is still a relatively new field of investigative work. It requires lengthy schooling for professional certification, is dependent on weather and temperature patterns, and can be impeded by a variety of physical conditions. However, it consistently provides a valuable insight into the origins of scavengers and colonizers of deceased individuals, helping investigators locate and identify persons unreachable by conventional searches. As it can also be used to confirm neglect or trauma, insect use can also help solve murder or rape investigations. Due to these benefits, it is a valuable and growing field of forensic work and should be utilized and studied whenever appropriate to continue improving field techniques and streamline insect identification.

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